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Valuation of information and the associated overpayment problem in peer-to-peer systems☆

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ABSTRACT

Most incentive schemes for peer-to-peer (P2P) file-sharing are rate-based, only giving consideration to upload rate when measuring contributions. Besides giving room for strategic peers to benefit from concealing high value chunks, rate-based metrics also aggravate overpayment. Overpayment is a phenomenon that one pays a higher than necessary price for goods. In a P2P system, overpayment exists because in most cases, the incentive schemes have design flaws. Specifically, in rate-based systems, bandwidth allocation policies ignore different values of different chunks, and it directly induces overpayment.

In this work, taking the chunk value in the reciprocity process into consideration, the overpayment problem in a BitTorrent network is investigated, and four side effects of overpayment are identified. A novel strategy called value-based BitTorrent (VBT) is proposed, which is found to be able to alleviate the degree of overpayment and consequently relieve the side effects of overpayment.

1. Introduction

Peer-to-peer (P2P) file-sharing systems have achieved outstanding success during the past two decades, in which every peer not only downloads from the system but also contributes to others. The more a peer contributes to the system, the higher reward it obtains. Incentive schemes therefore plays a crucial role in P2P file-sharing systems. Many different kinds of incentive schemes have been proposed [1–3]. Yet these incentive schemes still have some design flaws, manifested as: (1) loop-holes in policies, and (2) inadequate contribution measurement metrics. Indeed, much recent work has been done in investigating the deficiency of the existing incentive schemes. For instance, BitTyrant [4] and BitThief [5] take advantage of BitTorrent's unchoke policy and optimistic unchoke policy to gain benefit. Levin et al., [6] have tackled this problem, by designing a proportional sharing policy against these strategic behaviors.

We argue that the problem of using inadequate contribution measurement metrics could be an even more acute issue, which is unfortunately largely overlooked in practical systems. As in BitTorrent, most of the existing protocols for P2P systems use rate-based metrics to measure contributions. Specifically, a higher upload rate means a higher contribution level. Consequently, chunk value is neglected in these protocols. Indeed, these existing protocols are designed based on the premise that peers do not care about chunk values, which is unreasonable from an economic point of view. Rate-based metrics actually "motivate" strategic peers to game the system, by under-reporting their chunk maps, because reserving high value chunks can prolong their attractiveness in the long run [6].

Another serious problem about rate-based metrics is that they give rise to overpayment. When a peer pays prices higher than necessary for chunks, it overpays. The existence of overpayment degrades system performance. First of all, the amount of resource a peer overpays others can be used to sponsor other new transactions which can enlarge the system throughput. Secondly, poor peers might be crowded out because rich peers overpay for some chunks, making these chunks too expensive for them to obtain. Moreover, the existence of overpayment distorts the prices of chunks, and further hinders efficient resource allocation. Meanwhile, underpayment is always a consequence of overpayment, because there are peers gain extra advantage when some peers overpay. Thus, alleviating overpayment is critical for both the system and honest peers.

In BitTorrent, peers' contributions are measured by upload rate, without consideration of chunk value. Thus, many low value chunks are overpaid, while many high value chunks are underpaid. Underpayment on high value chunks slows the distribution speeds of high value chunks, degrading the system performance. In [7] and [8],

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chunk related policies are proposed to punish chunk map under-reporters. These works focus on improving the policies. We focus on the devise of one proper measurement indicator and the investigation of overpayment induced by rate-based metrics. We propose a value-based BitTorrent (VBT), in which peers unchoke others by their ranks of aggregated chunk value instead of upload rate to alleviate overpayment.

Another concern about overpayment is how to measure it. We find that, in BitTorrent, the correlation between peers' contributions, measured by aggregated chunk value, and return, measured by the fraction of the file successfully downloaded, shows an interesting pattern, called *light beam pattern* (LBP). Many interesting observations about an incentive scheme can be obtained from LBP. Moreover, we also use LBPs to visualize overpayment and underpayment in P2P file-sharing systems.

In this paper, we make the following contributions:

- Existing policy makers in P2P file-sharing systems all try to encourage peers to contribute more to the system. However, we find quantitatively that the existence of overpayment can degrade system performance and lead to strategic manipulation.
- We find that in BitTorrent, the correlation between peers' contributions and return follows a light beam pattern. Using this pattern, we can evaluate an incentive scheme's degree of overpayment and its resistance to manipulation behaviors.
- We propose two metrics to measure the degree of overpayment for P2P file-sharing systems, and also propose a value-based metric to alleviate the degree of overpayment in BitTorrent. The value-based metric can effectively punish strategic behaviors and alleviate overpayment degree in BitTorrent, leading to much better system performance.

In this work, we analyze the degree of overpayment in a BitTorrent network. We propose a novel value-based metric to value chunks, taking into consideration of chunk rarity. We find that the correlation between peers' investment, which is defined as the aggregate value of chunk they devote, and return, which is defined as the downloaded chunk volume, shows an interesting light beam pattern (LBP). We use LBPs to visualize the degree of overpayment in BitTorrent, compared with our proposed strategy, called value-based BitTorrent (VBT). We find that VBT has a lower level of overpayment and is consequently more robust to chunk map under-reporting behaviors. Our simulation results also show that after alleviating overpayment, the crowd-out effect is also significantly suppressed and the system performance is much better.

This paper is organized as follows. Section 2 provides the system model. A novel value-based metric is proposed to value chunks, taking into consideration of chunk rarity. Game theoretic analysis is used to illustrate the behavior of rational peers when value of chunks are considered. Section 3 illustrates the phenomenon of overpayment caused by rate-based metrics. Section 4 shows that the correlation between peers' investment, which is defined as the aggregate value of chunks they devote, and return, which is defined as the downloaded chunk volume, shows an interesting light beam pattern (LBP). In Section 5, we use LBPs to visualize the degree of overpayment in BitTorrent, compared with our proposed strategy VBT. Section 6 proposes two metrics to quantify overpayment. The simulation results are provided in Sections 7 and 8. Section 9 gives related works. We conclude in Section 10.

2. System model

Most incentive schemes for practical P2P file-sharing applications are rate-based. Rate-based metrics assume that all chunks have an identical value. However, in realistic P2P file-sharing systems, different chunks have different values for both the system and individual peers because of different characteristics of the chunks, e.g., the rarity. The distribution speeds of the rarest chunks in a system are the bottleneck of the distribution speed of a file [9]. Moreover, a peer tends to upload low rarity chunks instead of high rarity ones because concealing high rarity chunks prolongs their attractiveness in the long run [6]. Thus, higher rarity chunks should have higher values. Value of chunks should be considered in the incentive schemes because value of chunks is considered when rational peers making decisions. In this section, a game theoretic analysis is used to illustrate the behaviors of rational peers in strategic P2P file-sharing systems.

Table 1
Prisoner's Dilemma game in BitTorrent.

	Bob uploads high	Bob uploads low
Alice uploads high	$(u_a(H,H), u_b(H,H))$	$(u_a(H,L), u_b(H,L))$
Alice uploads low	$(u_a(L,H), u_b(L,H))$	$(u_a(L,L), u_b(L,L))$

2.1. Prisoners' Dilemma in BitTorrent

Suppose there are two peers, Alice and Bob, connected to each other in BitTorrent. Both of them unchoke each other during a time period. Each peer has a choice of revealing high rarity chunks or low rarity chunks to the other, and thus, each peer's set of action is $\{High, Low\}$. The payoff function u for Alice and Bob are the same. The game is illustrated in Table 1.

In a P2P file-sharing system, possessing more high rarity chunks means larger chance to gain more neighbors, usually leading to a higher download rate. Thus, the benefit of downloading a high rarity chunk is larger than that of downloading a low rarity one. Meanwhile, because uploading a high rarity chunk results in a higher chance to lose more interest among neighbors than uploading a low rarity chunk, the cost of uploading a high rarity chunk is larger than that of uploading a low rarity one. Consequently, Alice and Bob are both very glad to upload low rarity chunks more and downloading high rarity chunks more. Because a rate-based metric is used in BitTorrent for measuring contributions, the other peer will treat it the same no matter whether it uploads high rarity chunks or low rarity ones, provided the rate is the same. As a result, we can easily prove that in BitTorrent, for two collaborating peers, whether to uploading high rarity chunks or low rarity ones is a Prisoners' Dilemma game [10]. This is formalized by the following theorem.

Theorem 1. In BitTorrent, whether to upload high rarity chunks or low rarity ones to their counterparts is a Prisoners' Dilemma game.

Proof. Because uploading a high rarity chunk costs more than uploading a low rarity one, and downloading a high rarity chunk brings more benefit than downloading a low rarity one. Thus, we have $u(H,X) < u(L,X)$, and $u(X,H) > u(X,L)$, X can be H or L.

When both of them uploading high rarity chunks to the other, because the loss in attractiveness can be neutralized by the new chunk it just got, and meanwhile it obtains a high rarity chunk. Thus, the payoff of the two peers when both upload high rarity chunks is larger than that when both uploads low rarity chunks, i.e., $u(H,H) > u(L,L)$.

Thus, we can conclude that: For Alice,

$$u_a(L,H) > u_a(H,H) > u_a(L,L) > u_a(H,L) \quad (1)$$

For Bob,

$$u_b(H,L) > u_b(H,H) > u_b(L,L) > u_b(L,H) \quad (2)$$

Thus, this game is a Prisoners' Dilemma. □

Because it is a Prisoners' Dilemma in BitTorrent, there is only one Nash equilibrium of this game: Both of them upload low rarity chunks